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EVALUATION OF THE CREVICE CORROSION SUSCEPTIBILITY OF STAINLESS STEELS AVESTA 254 SMO

FINAL REPORT

BY

Dearborn Environmental Consulting Services

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SUMMARY

This report describes the testing of nine different materials to cause crevice corrosion on wrought stainless steel, AVESTA 254 SMO. These materials were elastic bands, elastic pieces, glass, AVESTA, Teflon, Delrin, nylon and wood. In addition the effect of surface abrasion was evaluated.

Elastic bands on abraded surfaces produced the most rapid corrosion causing complete failure of the coupons by 35.0°C. Elastic bands on unabraded surfaces produced rapid corrosion causing complete failure of the coupons by 37.5°C. Elastic pieces produced complete failure at 47.5°C, Teflon and nylon at 55.0°C, glass at 60.0°C and Delrin completely failed at 65.0°C. Total failure did not occur when wood and AVESTA were used as crevice materials. Results of the testing indicate that the onset of corrosion caused by these different materials is related to temperature and the nature of the materials.

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1. INTRODUCTION

Corrosion in simple terms is a deterioration of a substance (usually a metal) or its properties due to the effect of unwanted chemical reactions placed upon it. In a liquid environment the source of these reactions is electrochemical. An anode and cathode are established with the liquid environment acting as an electrolyte.

The most common failure mode of stainless steels exposed to acid chloride solutions is localized corrosion, particularly crevice corrosion. Some highly alloyed stainless steels are known to resist crevice corrosion in a solution such as 10 per cent ferric chloride (10% $FeCl_3$) at low temperatures, but fail at higher temperatures. The go/no go temperature for the onset of crevice corrosion is believed to vary slightly from stainless steel sample to sample and to be subject to a statistical variation of approximately $\pm 5^{\circ}C$. In addition, the choice of material which forms the crevice with the stainless steel, whether wood, nylon, Teflon etc. is believed to have a pronounced effect on the statistically determined crevice corrosion temperature.

Dearborn Environmental Consulting Services was retained by the Department of Energy, Mines and Resources, Physical Metallurgy Research Laboratories to investigate the effects of different crevice materials on the crevice corrosion of AVESTA wrought stainless steel and to determine the temperature at which the onset of crevice corrosion occurs.

2. OBJECTIVES

The objectives of this study were to test nine different materials for their ability to cause crevice corrosion with coupons of AVESTA stainless steel and to determine the temperature at which the corrosion occurred.

The materials tested were:

- Elastic Bands
- Elastic Pieces
- Glass
- AVESTA
- Teflon
- Delrin
- Nylon
- Wood
- Abraded and Elastic Bands

3. PROCEDURES

The nine different crevice materials were tested in separate containers using assemblies consisting of ten coupons and eleven units of crevice materials. Schematic drawings of the assemblies are shown in Appendix I.

Pre-Exposure Preparation

AVESTA Coupon Preparation

A sheet of AVESTA 254 SMO Stainless Steel* was sheared to provide 1000 coupons with approximate dimensions of 15 x 30 x 2 mm. The faces of the coupons were abraded with 210 grit silicon carbide (SiC). The edges of the coupons were also abraded and rounded with 120 grit silicon carbide (SiC) grinding wheels using a high speed industrial grinder. This process removed all cold work arising from the shearing operation.

The bare coupons were exposed to a solution of 10 percent ferric chloride ($FeCl_3$) in plastic rectangular sealed containers for 64.5 hours at room temperature (20.5°C). The ferric chloride solution was prepared by dissolved 3000 g of $FeCl_2.6H_2O$ in 15 litres of distilled water. At the end of this period there was no evidence of any form of corrosion on the coupons.

Crevice Material Preparation

The crevice materials were prepared in the following manner. Rubber pieces were cut from large elastic bands with approximate dimensions of 15 x 15 x 1.5 mm.

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* See Appendix II for chemical analysis and other technical information regarding the AVESTA steel characteristics.

Microscope slides were used for the glass crevice material while the plastic and wood pieces were cut from strips of the material as supplied by their manufacturers. The elastic bands were not altered for the testing.

All the materials were soaked in a 10 percent $FeCl_3$ solution for 48 hours at 20.0°C under the same conditions as the corrosion coupons.

Exposure Procedure

The assemblies were placed in the plastic containers and totally immersed in the ferric chloride solution. The containers were sealed to prevent water evaporation and resulting concentration of $FeCl_3$. The first exposure group consisted of:

100 Elastic Bands
100 Elastic Pieces
100 Glass
100 AVESTA

These four containers were placed in the incubator (Thelco GCA/Precision Scientific) at 30.0°C ($\pm$ 0.5°C) to begin the 24-hour exposure period. On the following day, 24 hours later, the first exposure group was removed from the incubator and the second exposure group was inserted. This second group consisted of:

100 Teflon
100 Delrin
100 Nylon
100 Wood
100 Abraded and Elastic Bands

The first exposure group was then rinsed in deionized water and the assemblies were taken apart. Each coupon was inspected for any form of corrosion on either surface or on any edge. Any corrosion was noted and described with notable observations being recorded. Any coupon which showed corrosive attack was set aside and the $FeCl_3$ solution was reused.

The incubator was set at one temperature for 2 days. However, on the second day of each temperature, 1 hour before the exposure group was removed from the incubator, the temperature setting was increased to the next test condition temperature in order to ensure a 24-hour exposure at the new reading for the next incoming exposure group. The second exposure group was rinsed in deionized water, taken apart, and inspected for corrosion. Again, if any coupon showed corrosive attack, it was set aside and the $FeCl_3$ solution was replaced.

4. TECHNICAL DISCUSSION

The rates of failure of the coupons and notable observations are described in this section of the report. Table 1 contains the percentage cumulative failure versus temperature for the nine materials tested. The same data presented in graphical form appears on Figures 1 through 9.

When using elastic bands as the crevice material, corrosion began at 30.0°C and total failure occurred at 37.5°C. The corroded areas were white in colour. Most of the corrosion originated at the edge and extended towards the centre. Some of the coupons had only surface corrosion. The corroded areas of all the coupons appeared as narrow strips and appeared only in areas of contact between the elastic band and the coupon. The elastic bands turned orange-brown in colour.

Crevice corrosion, using elastic pieces first occurred at 32.5°C and total failure occurred at 47.5°C. Staining of both the elastic pieces and the coupons was evident. Corrosion, at lower temperatures, appeared as white areas covering most of the area of contact. As the temperatures increased it became more difficult to separate the coupons from the elastic pieces and the $FeCl_3$ solution was murky brown. Corroded areas, at higher temperatures, occurred as deep crevices with a black outline within a white area of attack.

Initial corrosion was noted at 40.0°C when glass was used as the crevice material, however, significant corrosion did not occur until 55.0°C. Total failure came about at 60.0°C. As the temperature increased, the glass was stained yellow except for a clear area where the coupon made contact. Corrosion appeared as white areas with some black streaks originating at the borders and spreading over the entire area of contact

on some coupons. The $FeCl_3$ solution became murky-brown as the temperatures increased.

When AVESTA was used as a crevice material, corrosion first occurred at 52.5°C. Six coupons remained uncorroded after 65.0°C. Staining of AVESTA was evident from 50.0°C and higher. The metal became yellow where it was exposed to the $FeCl_3$ solution. Crevice corrosion most often covered the entire area of contact, producing deep crevices at the higher temperatures. The $FeCl_3$ solution turned murky green-brown in colour.

Teflon as a crevice material caused corrosion to first occur at 35.0°C. Total failure resulted at 55.0°C and at this temperature the $FeCl_3$ solution was murky green-brown. The Teflon was stained yellow except where the coupon was in contact, where it remained white. Corroded areas appeared as small shiny white areas at lower temperatures and as larger areas of attack on the surface and the perimeters of contact surfaces at higher temperatures.

The coupons with Delrin as the crevice material resisted corrosion until 52.5°C. Total failure was reached at 65.0°C. Delrin stained yellow but remained white where metal coupon was in contact. At higher temperatures (62.5°C and 65.0°C) the yellow stain would easily rinse off with deionized water. Corroded areas involved the surface and were white in colour with some black streaking. The $FeCl_3$ solution turned murky green-brown.

The nylon crevice material reacted much the same was as did the Teflon. Total failure occurred at 55.0°C with the first sign of corrosion occurring at 42.5°C. The $FeCl_3$ solution was changed to a murky green-brown colour.

Wood, used as a crevice material, produced the only test condition, other than AVESTA, not to completely fail. Initial corrosion occurred at 47.5°C. The brown brittle pieces of wood, when immersed in the $FeCl_3$ solution became more pliable and changed to a green-brown colour. Corrosion occurred as shiny white areas on the surface and the perimeter of contact surfaces. The $FeCl_3$ solution at 65.0°C was dark green in colour.

The last crevice material used was elastic bands wrapped tightly around the coupon, which had been lightly abraded one hour before exposure. 50 percent of the coupons corroded at the initial exposure temperature of 30.0°C. Total failure occurred at 35.0°C. The abraded surface with elastic bands demonstrated the most rapid corrosion rate. Corroded areas appeared as white shiny narrow strips of attack.

TABLE 1. DISTRIBUTION OF FAILED COUPONS FOR THE NINE MATERIALS TESTED

Temperature °C	CREVICE MATERIAL																	
	Elastic Bands		Elastic Pieces		Glass		AVESTA		Teflon		Delrin		Nylon		Wood		Abraded and Elastic Bands	
	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure	Number Failed Coupons	Cumulative Percent Failure
10.0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	50
12.5	51	61	13	13	0	0	0	0	0	0	0	0	0	0	0	0	38	88
15.0	25	86	28	41	0	0	0	0	1	1	0	0	0	0	0	0	12	100
17.5	12	100	5	46	0	0	0	0	0	1	0	0	0	0	0	0		
40.0			11	58	6	6	0	0	0	1	0	0	0	0	0	0		
42.5			18	75	0	6	0	0	0	1	0	0	2	2	0	0		
45.0			21	96	0	6	0	0	3	4	0	0	4	6	0	0		
47.5			4	100	0	6	0	0	6	10	0	0	1	7	1	1		
50.0					0	6	0	0	20	30	0	0	15	22	2	3		
52.5					54	60	17	17	51	81	33	33	17	39	0	3		
55.0					23	83	14	31	19	100	20	53	61	100	40	43		
57.5					8	91	25	56			16	69			6	49		
60.0					9	100	16	72			29	98			10	59		
62.5							13	85			1	99			9	68		
65.0							9	94			1	100			10	78		

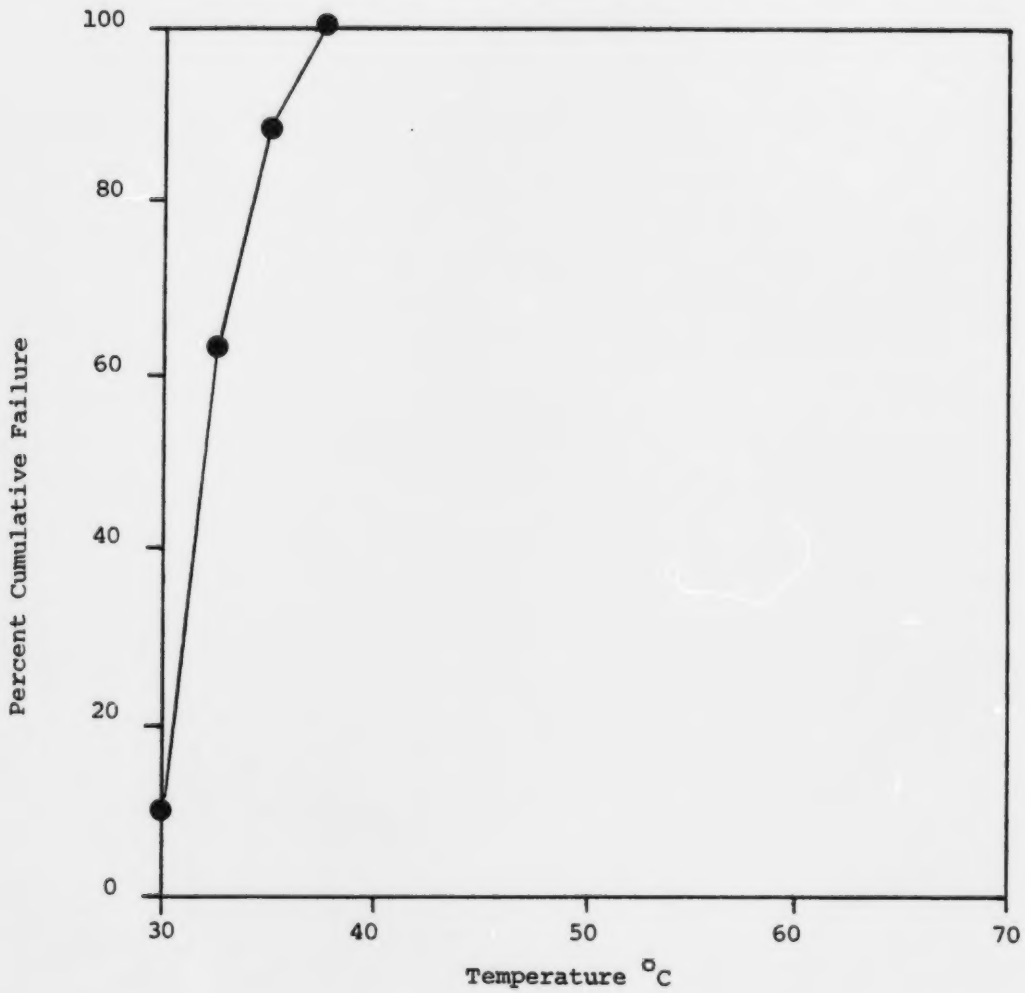


FIGURE 1. EFFECT OF TEMPERATURE ON CORROSION OF TEST COUPONS - ELASTIC BANDS

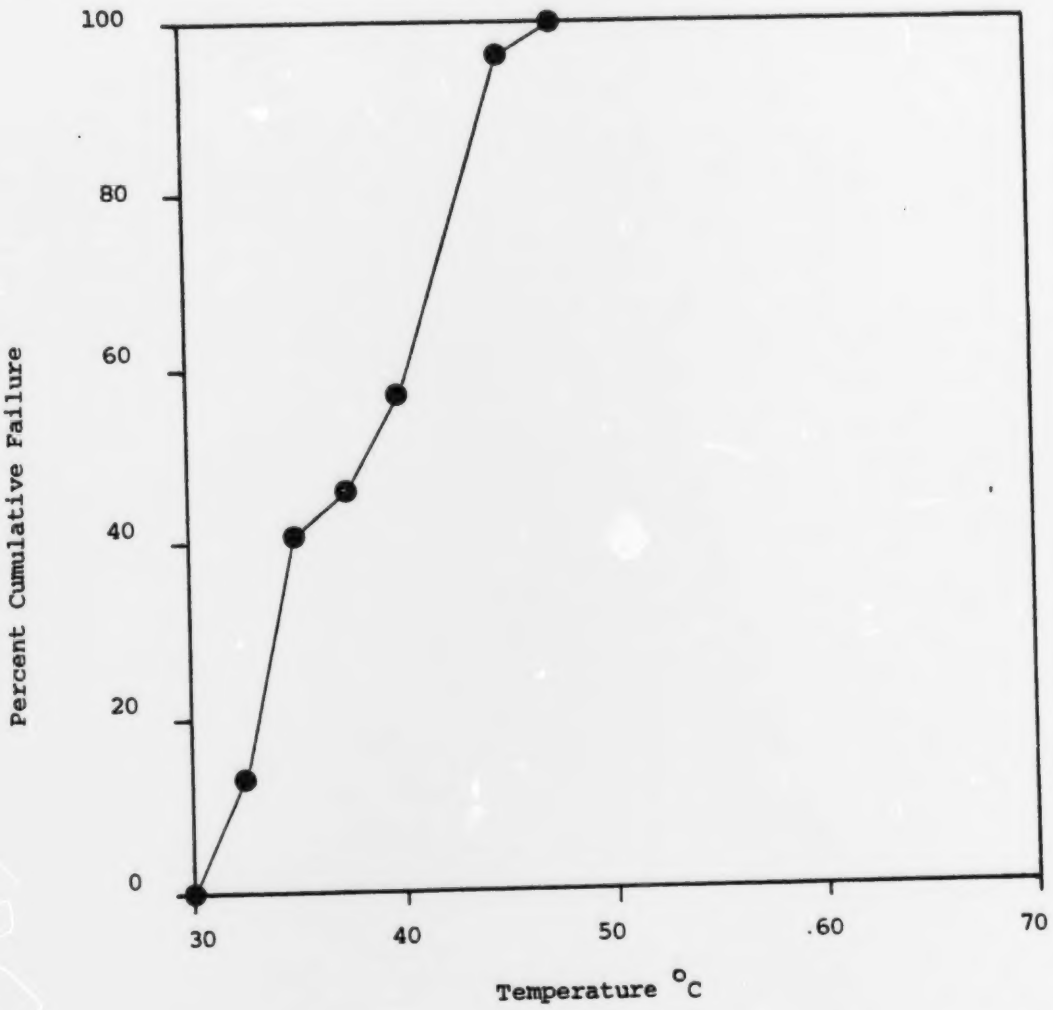


FIGURE 2. EFFECT OF TEMPERATURE ON CORROSION OF TEST COUPONS - ELASTIC PIECES

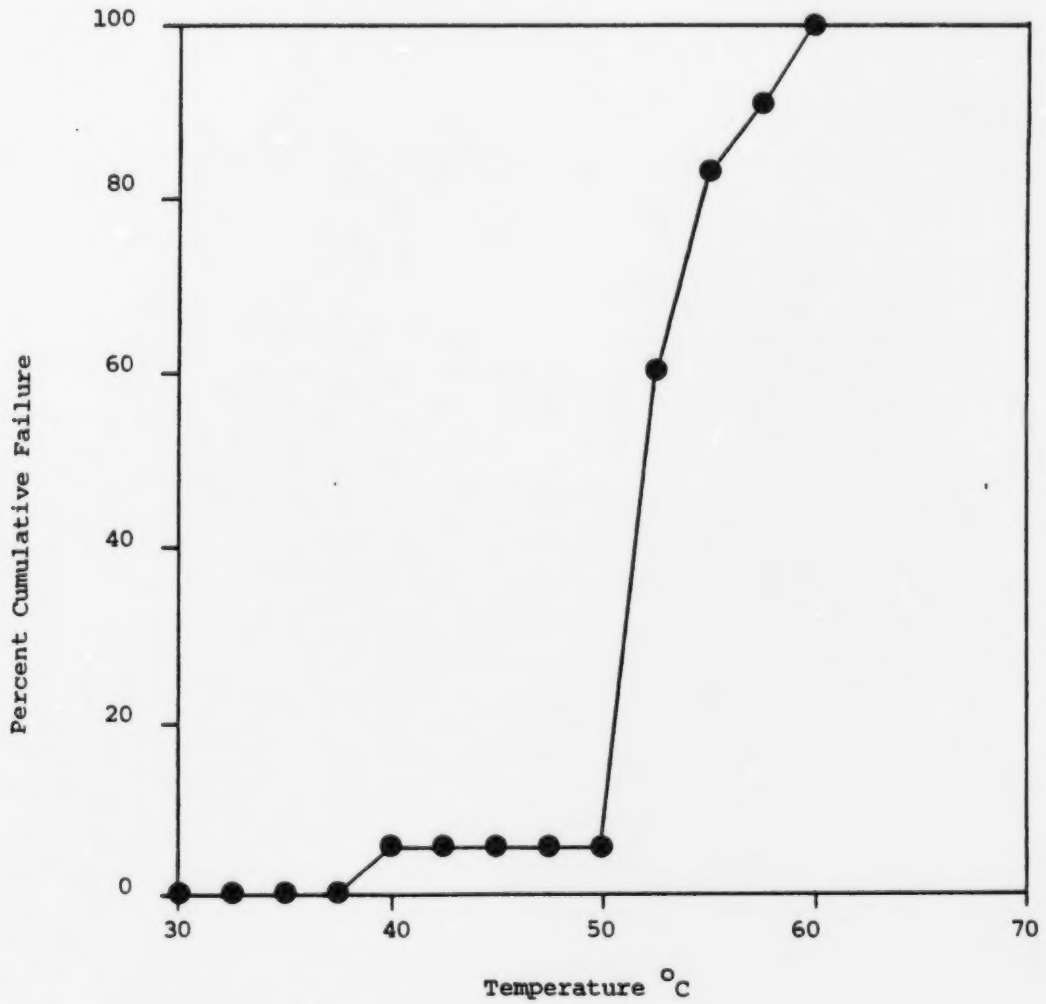


FIGURE 3. EFFECT OF TEMPERATURE ON CORROSION OF TEST COUPONS - GLASS

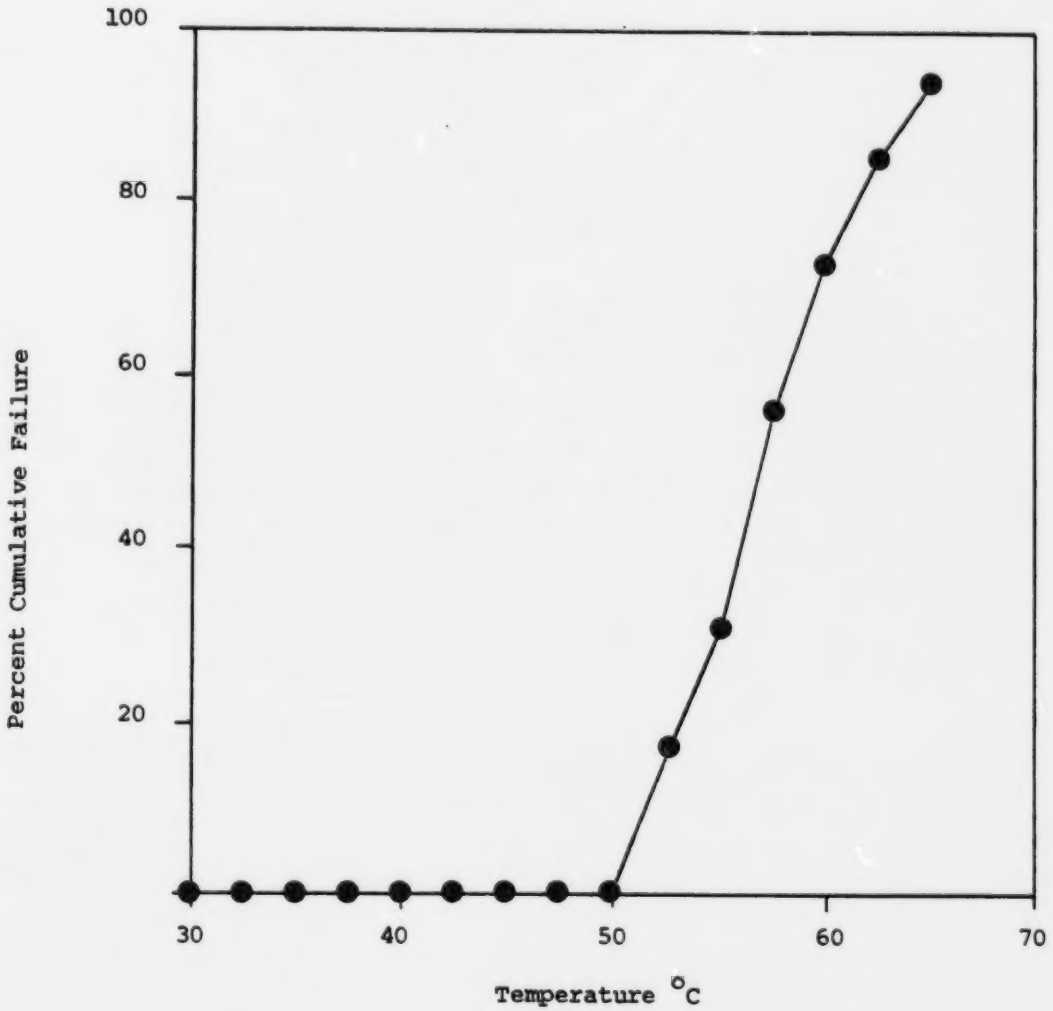


FIGURE 4. EFFECT OF TEMPERATURE ON CORROSION OF TEST COUPONS - AVESTA

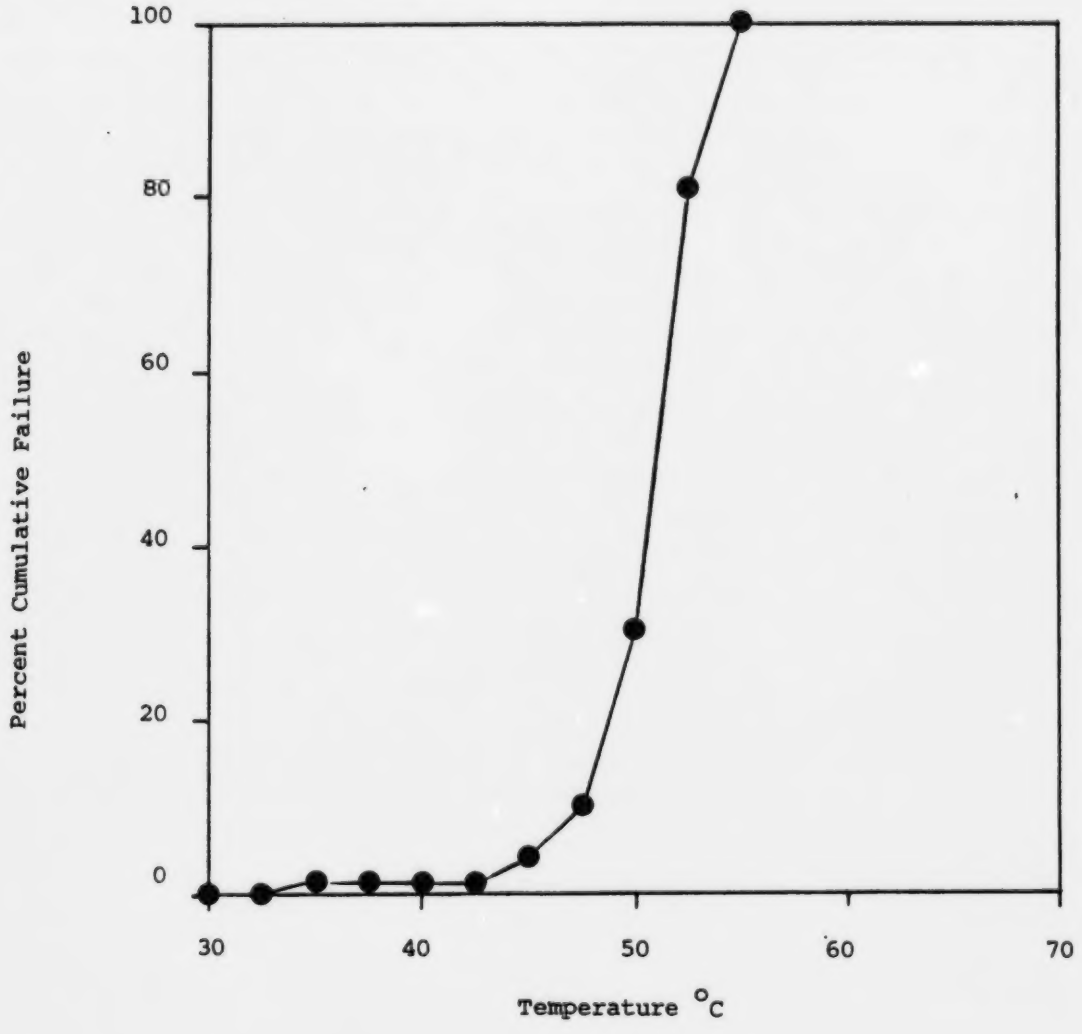


FIGURE 5. EFFECT OF TEMPERATURE ON CORROSION ON TEST COUPONS - TEFLON

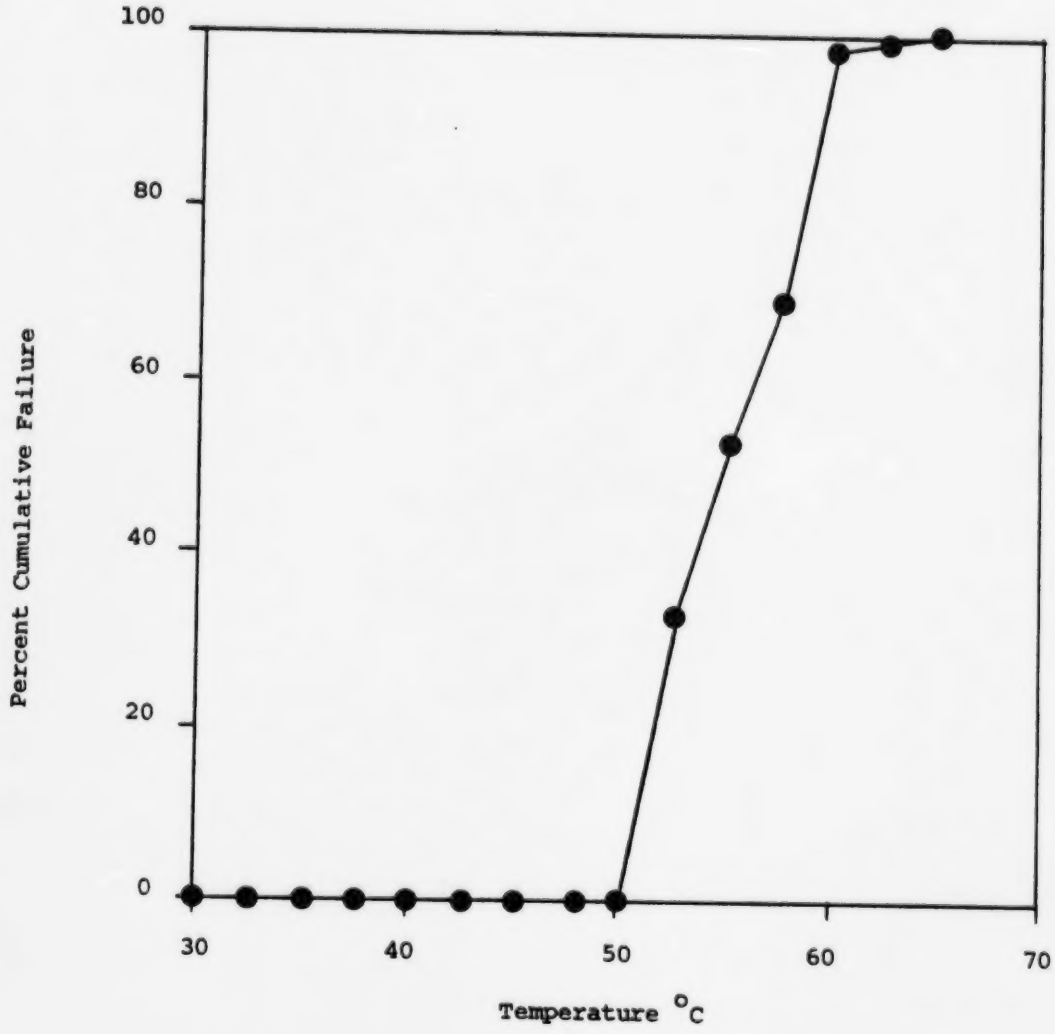


FIGURE 6. EFFECT OF TEMPERATURE ON CORROSION OF TEST COUPONS - DELRIN

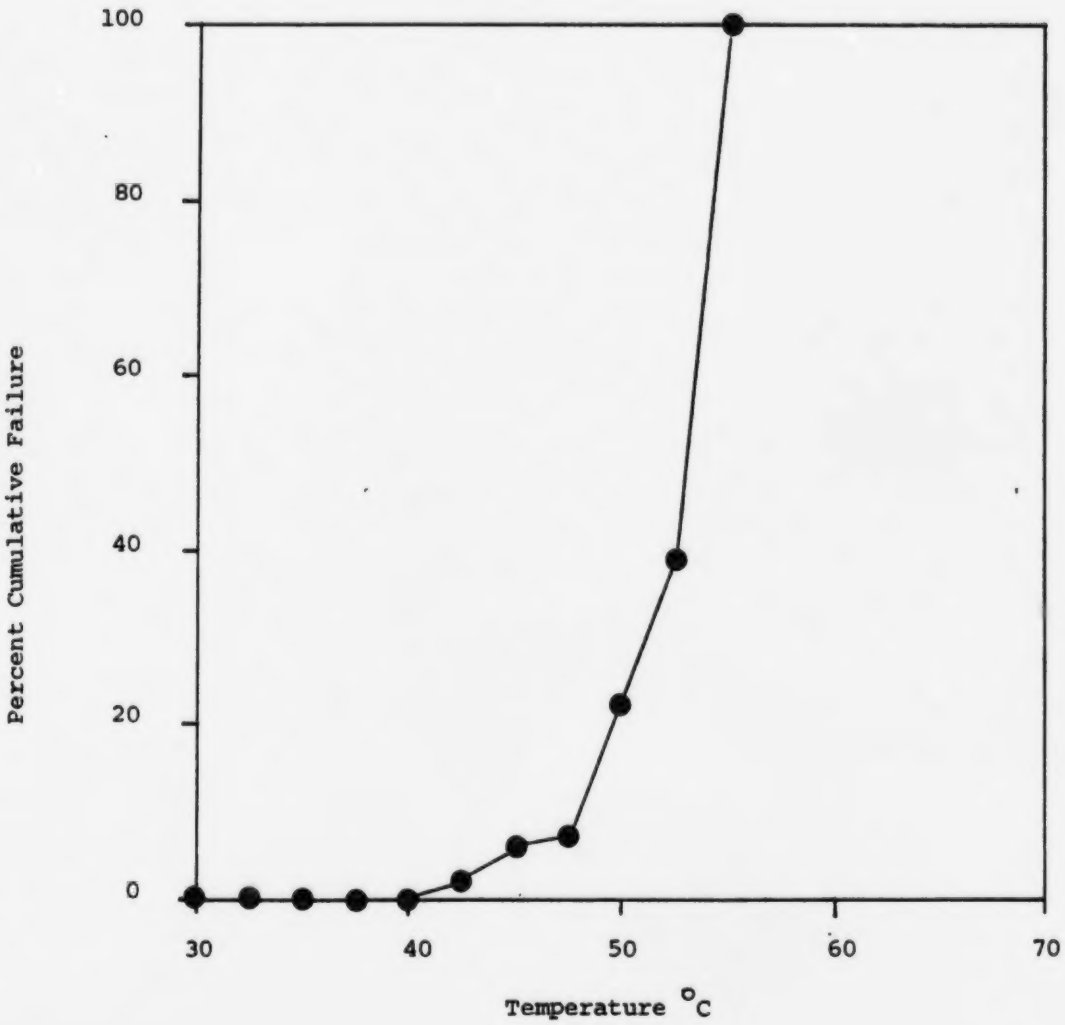


FIGURE 7. EFFECT OF TEMPERATURE ON CORROSION OF TEST COUPONS - NYLON

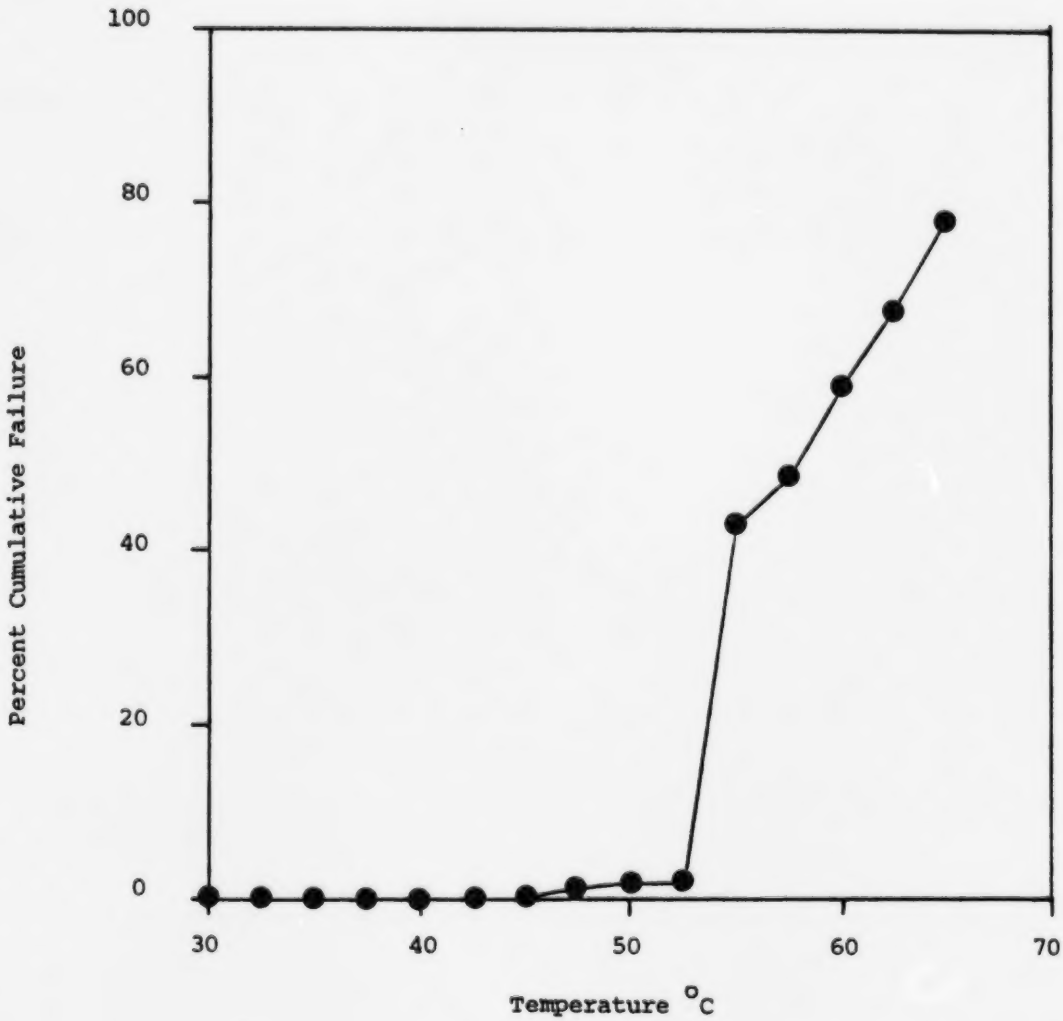


FIGURE 8. EFFECT OF TEMPERATURE ON CORROSION OF TEST COUPONS - WOOD

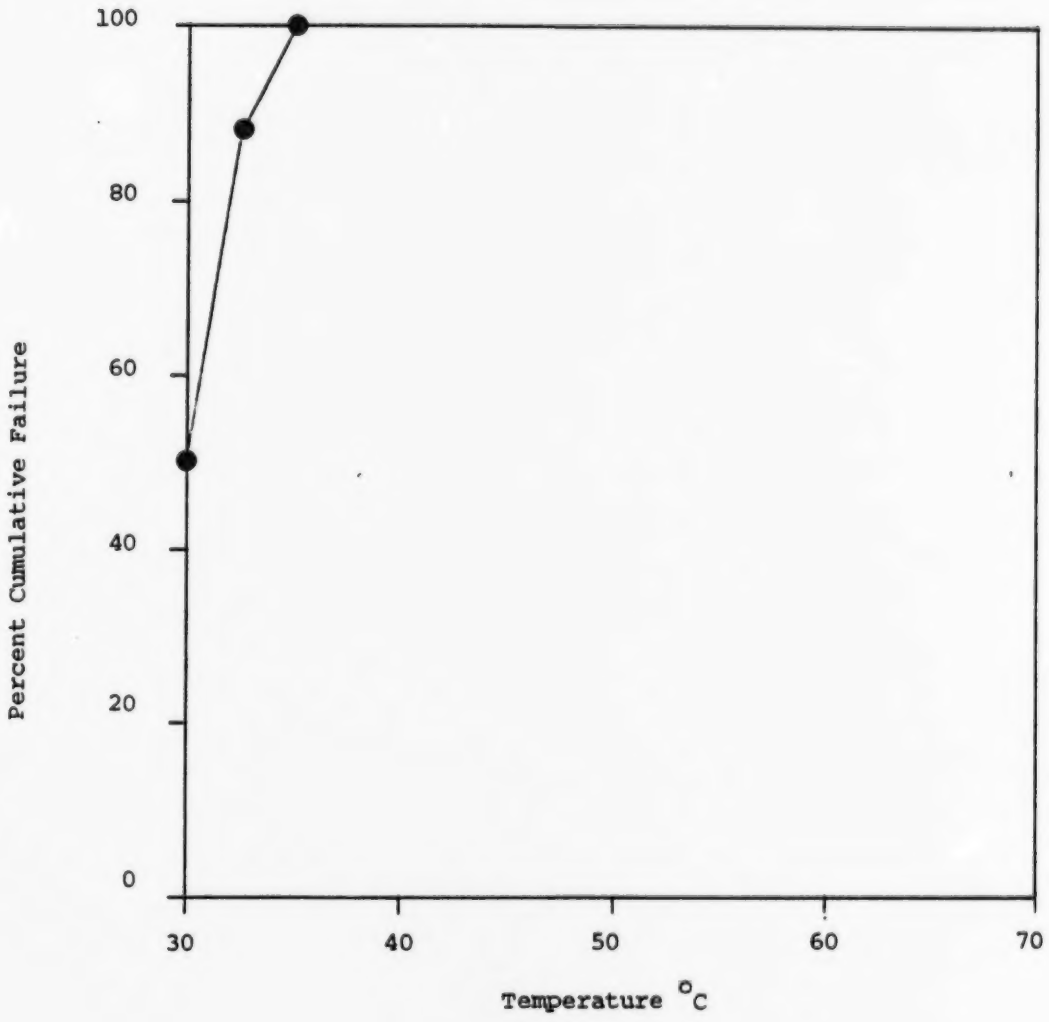


FIGURE 9. EFFECT OF TEMPERATURE IN CORROSION OF TEST COUPONS - ABRADED ELASTIC BANDS

5. CONCLUSIONS

Based on the results of this study the following conclusions can be drawn:

- The onset of crevice corrosion depends on the nature of the crevice material and the temperature of exposure

- The appearance of the corrosion attack on the metal is dependent on its surface texture and to some extent on the nature of the crevice material.

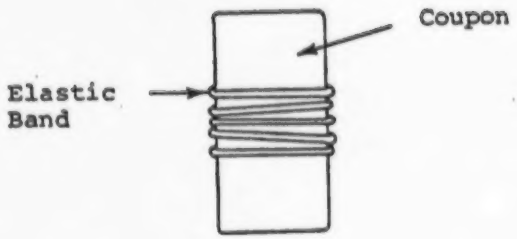
- Elastic bands appeared to be the most corrosive when wrapped around the coupon, especially if the coupon was lightly abraded prior to exposure.

- The order at which total failure occurred, caused by the remaining materials, appears to be: elastic pieces, Teflon and nylon, glass, Delrin, AVESTA and wood.

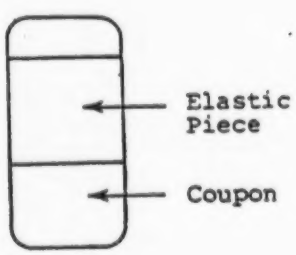
- AVESTA and wood used as crevice materials did not completely fail under test conditions.

APPENDIX I

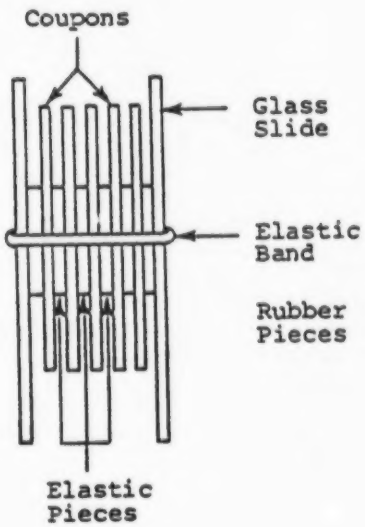
CONFIGURATIONS OF CORROSION TEST ASSEMBLIES USED DURING THE STUDY



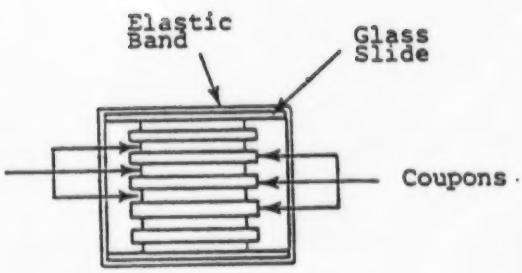
ELASTIC BANDS WRAPPED AROUND
6 TIMES



ELASTIC
PIECES

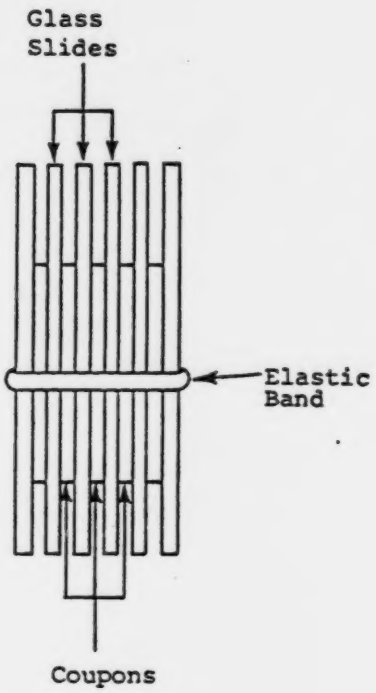


SIDE VIEW

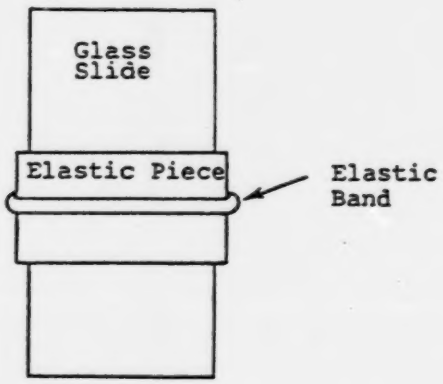


TOP VIEW

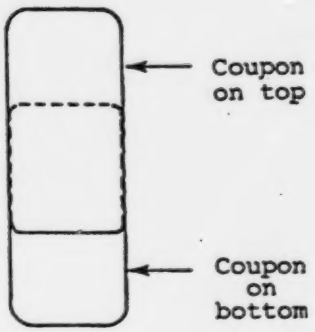
Pieces of elastic band touching faces of coupons only, held in place by glass microscope slide, tensioned by encircling elastic bands not touching metal.

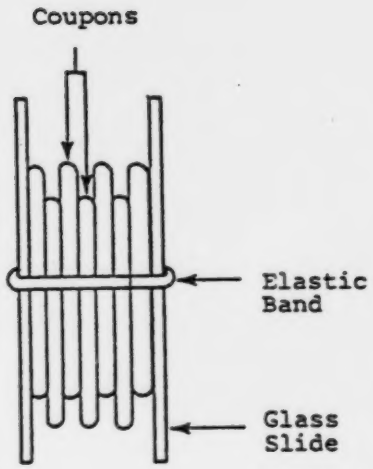


Glass - metal coupon sandwiched between two glass microscope slides tensioned by encircling elastic band.

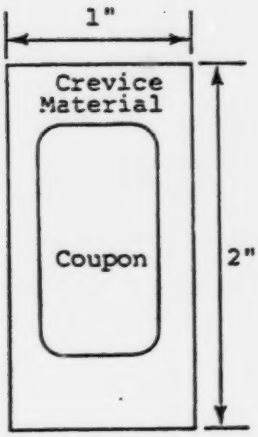


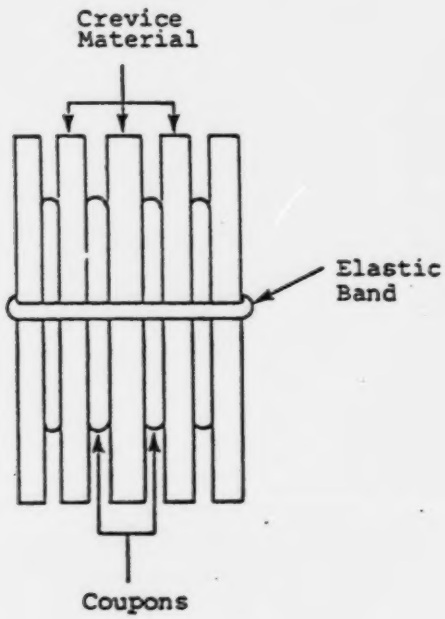
In order to prevent the glass slides from cutting the tensioning elastic bands, a piece of large elastic band was placed between the glass slide and elastic band.





AVESTA - metal to metal crevice between two glass microscope slides tensioned by encircling elastic bands.





Teflon
Nylon
Delrin
Wood

metal coupon sandwiched between two pieces of crevice material tensioned by encircling elastic bands not touching metal.

APPENDIX II

CHARACTERISTICS OF AVESTA 254 SMO STEEL

Element in Stainless Steel	Percent Composition
carbon	0.020
silicon	0.4
manganese	0.5
sulphur	0.005
chromium	20.0
nickel	18.0
molybdenum	6.1
copper	0.7
nitrogen	0.2

Tensile Properties	
yield strength (N/mm^2)	320
Tensile strength (N/mm^2)	650 - 750
elongation (%; $L = 5.65\sqrt{A}$)	50
Hardness HV	200
Hardness HB	175

AVESTA TECHNICAL INFORMATION

AVESTA 254 SMO —

A NEW, HIGH MOLYBDENUM STAINLESS STEEL

by Bengt Wallén and Mats Liljas,
Avesta Jernverks AB

AVESTA 254 SMO - A NEW, HIGH MOLYBDENUM STAINLESS STEEL

by Bengt Wallén and Mats Liljas, Avesta Jernverks AB,
S-77401 Avesta, Sweden

Paper presented at NKM 8, Helsinki, August 1978

1 SUMMARY

The corrosion properties of a new, commercially available, austenitic stainless steel are described. The new steel, which contains 6.1 % molybdenum, possesses excellent properties in halide solutions and in acids contaminated by halides. Laboratory tests show that the resistance towards pitting and crevice corrosion is far superior to that of the standardized steels and is close to that of the best nickel alloys.
Tests in field related media confirm that the new steel can be used in applications where even the highest alloyed standardized stainless steels have marginal resistance.

2 WAYS OF EVALUATING THE CORROSION PROPERTIES OF A NEW MATERIAL

When evaluating the corrosion properties of a new stainless steel different methods can be used. Laboratory testing is often simple to carry out and it produces quick results. Furthermore laboratory tests permit a close control of the test parameters and therefore they are reproducable. However, many laboratory tests are accelerated and the test solutions have no practical equivalents. This is especially true for the tests concerning localized corrosion. Therefore the results obtained from tests using these artificial media are rarely directly applicable. On the other hand most accelerated tests are well suited for classification of the steel investigated in relation to other alloys the practical behaviour of which is well known.
In other laboratory tests environments are used that correspond to service media. These tests give a more reliable basis for the choice of a suitable alloy in the practical cases but they are not as generally applicable as the former tests. Evaluating the corrosion properties of a stainless steel by using tests only in service related media is very time-consuming.
When selecting a steel grade for one specific process, the most reliable results are obtained if the test is carried out under service conditions in the actual process. This is time consuming, however, and a close control of the parameters important to corrosion is seldom feasible. Therefore the experiences gained in one process are not always transferable to a similar one. This is certainly so if the environment is corrosive as a result of impurities, the amount of which varies from case to case. To get a complete picture of the properties of the new material, both classification and service related tests should be used.

3 CLASSIFICATION OF CORROSION PROPERTIES

In the tests included in this and following chapters, Avesta 254 SMO is always compared with at least two of the alloys presented in table 1.

Alloys	Typical composition, % w/w					
	C max	Cr	Ni	Mo	Cu	Others
SIS 2343, AISI 316	0.05	17	11.5	2.7		
SIS 2353, AISI 316L	0.030	17.5	13	2.7		
SIS 2367, AISI 317L	0.030	18	15	3.5		
W.Nr 1.4439	0.030	17.5	13.5	4.5		N 0.14
SIS 2562	0.020	20	25	4.5	1.5	
Avesta 254 SMO	0.020	20	18	6.1	0.7	N 0.20
A	0.050	21	42	3.0	2.2	Ti
B	0.10	21	Bal.	9.0		Nb, Fe<5
C	0.020	16	Bal.	16		W 3.5, Fe 5.5
D	Commercially pure titanium, ASTM B265 Grade 1					

Table 1: Chemical composition of tested alloys

These alloys consist of six stainless steels, three nickel base alloys, and pure titanium. In some tests in field related media welded samples were used, the weld metal having the same composition as the parent metal. Like the other stainless steels Avesta 254 SMO is completely austenitic. The main feature of Avesta 254 SMO is its very high molybdenum content.

3.1 Pitting corrosion

The most frequent tests used to classify pitting resistance are electrochemical pitting potential measurements and determination of the critical pitting temperature (CPT) in an acidic $FeCl_3$ solution. Tables 2 and 3 show some results of these test methods.

Alloy	Pitting potential, mV SCE			
	25°C	50°C	70°C	90°C
SIS 2343	385	235	90	40
SIS 2562	>1000	570	310	235
Avesta 254 SMO	>1000	>1000	970 ±65	685 ±135
A	not tested		215	185
B	not tested			585
C	"			575
D	"			>1000

Table 2: Pitting potentials in 1M NaCl.
Potentiodynamic method. Scanning rate 20 mV/min

Alloy	CPT °C
SIS 2353	14
SIS 2562	42
Avesta 254 SMO	87

Table 3: Critical pitting temperature in $FeCl_3$ according to ASTM G 48-76 Ref (1-2)

The figures presented in table 2 for Avesta 254 SMO are the mean values and the maximum deviation obtained for plate material from four commercial heats. A high pitting potential and a high CPT indicate an excellent resistance to the initiation of pitting corrosion for Avesta 254 SMO.

3.2 Crevice corrosion

The same kind of test methods are used to evaluate both crevice corrosion resistance and pitting, the difference being that the test samples in the former case are equipped with crevices created by pressing a polymer surface against the sample. Tables 4 and 5 show the crevice corrosion potential and the critical crevice corrosion temperature (CCT) for some alloys. In the latter test, crevices are formed on the face of each sample by a polymer rod held in place by two rubber bands, which themselves form four edge crevices.

Alloy	Crevice corrosion potential, mV SCE
SIS 2343	145
SIS 2562	290
Avesta 254 SMO	710 ± 160
C	625

Table 4: Crevice corrosion potentials in 0.1 M NaCl at 25°C. Potentiostatic method. 60 h per 25 mV. PTFE crevices

Alloy	CCT, °C	
	Face	Edge
SIS 2343	<15	<15
SIS 2562	20	<15
Avesta 254 SMO	45	32.5
A	<15	<15
B	>50	42.5
C	>50	45

Table 5: Critical crevice corrosion temperature in $FeCl_3$ according to ASTM G 48-76

As is the case with table 2, the result for Avesta 254 SMO in table 4 consists of the mean value for different commercial heats and the maximum deviation. Also in these tests, Avesta 254 SMO proved superior to the other stainless steels investigated. It should be observed that crevice corrosion occurs at a lower temperature on the edges than on the faces of the samples.

If the crevice and pitting corrosion potentials are compared it is obvious that the former are considerably lower in spite of the test solution being more dilute, i.e. less aggressive, in the crevice corrosion test. Similarly the CCT is much lower than the CPT in the same solution. This is completely in accordance with practical experience. In sea water, for instance, the main corrosion hazard is not pitting corrosion on free surfaces but attacks under crevices formed by deposits or marine growth.
Crevice corrosion initiates by the formation of a strong acidic chloride solution within the crevice (3). Therefore an alloy which has a good resistance towards such solutions can be expected to have a good resistance also towards the initiation of crevice corrosion. In fact a crevice corrosion test method based on this has been developed (4). In this method one determines at which pH an active peak starts appearing at anodic polarization in a chloride solution. Table 6 shows the so called "pH of depassivation" for some alloys.

Alloy	pH
SIS 2343	2.5
A	2.1
SIS 2562	1.6
C	0.8
Avesta 254 SMO	0.6
B	0.2

Table 6: pH of depassivation in 2M NaCl at 25°C. N_2 saturation. Criterion $\geq 10\,\mu A/cm^2$

The very low pH value for Avesta 254 SMO confirms its excellent crevice corrosion properties.

3.3 Stress corrosion cracking

In Swedish laboratories, two accelerated test methods are in common use, both employing concentrated chloride solutions. Tables 7 and 8 present the time to fracture for uniaxial testing in the two test solutions.

Alloy	Time to fracture h
SIS 2343, AISI 316	450
SIS 2562	>3000
Avesta 254 SMO	>3000

Table 7: SCC in 40% $CaCl_2$ at 100°C
pH 6.0, O_2 saturation
Stress: 2/3 · Rp0.2 at 100°C

Alloy	Time to fracture h
SIS 2343, AISI 316	5
SIS 2562	70
Avesta 254 SMO	27

Table 8: SCC in $MgCl_2$ solution boiling at 154°C
Stress: 2/3 · Rp0.2 at 150°C

The $MgCl_2$ test has been criticized because it classifies different steel grades in a way that is not in accordance with practical experience (5). For instance, this test method indicates a negative effect of molybdenum while other test methods and practical experience show a positive effect of a high molybdenum content (6, 7). The results of the tests show that Avesta 254 SMO, although not immune to SCC, is far more resistant than SIS 2343 and is on level with SIS 2562 which has a very good practical record.

4 INFLUENCE OF WELDING ON CORROSION PROPERTIES

Avesta 254 SMO is fully austenitic after annealing at 1150°C. When the material is held in the temperature range 600-1000°C second phases precipitate. As the 254 SMO has a very low carbon content (max C.020 %) carbide precipitation is very sluggish and the steel is not susceptible to intergranular corrosion caused by chromium rich carbides. Samples which have been sensitized at temperatures between 600 and 1000°C for up to one hour pass the Strauss test (SIS 117105 or ASTM A 262 practice E). If welded under normal procedures and with low heat input there is no risk of any preferential corrosion attack in the heat affected zone.

As shown by Garner (2) weld metal of high molybdenum stainless steels could have a decreased pitting and crevice corrosion resistance when compared with the base metal of the same composition. This is explained by microsegregations originating from the solidification. The first crystals or dendrites solidifying from the melt are normally depleted in alloy content especially in molybdenum. The last parts to solidify are consequently enriched in alloy content. Micro probe measurements of some weld metals produced by TIG welding of 3 mm sheet are found in table 9.

Parent Metal	Filler metal	Weld composition, % w/w Average		Dendrite centre	
		Cr	Mo	Cr	Mo
SIS 2562	SIS 2562	20.1	4.7	19.3	3.8
254 SMO	254 SMO-6Mo	19.9	6.1	19.1	4.8
254 SMO	254 SMO-9Mo	20.2	8.3	20.2	6.8

Table 9: Alloy distribution in austenitic welds

The table reveals that the depletion in dendrite centres is most pronounced for molybdenum. As this element has a strong effect on pitting and crevice corrosion resistance the attacks should initiate in the dendrite centres which has also been shown by Garner (2). Critical crevice corrosion temperatures for some alloys extracted from his curves are shown in table 10.

Alloy	CCT (face), °C	
	Parent metal	Weld metal
SIS 2353, AISI 316L	< -5	< -5
SIS 2367, AISI 317L	< -5	< -5
SIS 2562	7	7
Avesta 254 SMO	44	32

Table 10: Critical crevice corrosion temperatures of welded samples in $FeCl_3$ solution according to ASTM G 48-76 Ref (2)

The weld metal was produced by automatic TIG welding with no external filler wire. Corrosion tests on TIG welds of 254 SMO with two different filler wires also illustrate the effect of weld metal segregation (table 11).

Type of filler metal	Pitting potential 1M NaCl, 70°C, mV SCE
254 SMO-6Mo	600
254 SMO-9Mo	955
254 SMO parent metal	975

Table 11: Pitting potentials of Avesta 254 SMO weld metal produced by different filler wires

The weld metal produced by 254 SMO-6Mo filler metal has a decreased pitting potential compared to the parent metal but the level is still very high if one compares with that of SIS 2562 (310 mV according to table 2). By using a higher alloyed filler metal like 254 SMO-9Mo the very high pitting potential of Avesta 254 SMO parent metal is maintained. Similar results are obtained with metal arc welding.

The results of service and corrosion tests (cf. paragraphs 5.1, 5.2 and 5.4) have shown that Avesta 254 SMO has a very high resistance also in the welded condition. As with other high molybdenum stainless steels, a weld metal of the same composition as the parent metal is the most corrosion prone area in chloride solutions. Although this weld metal still has a high corrosion resistance compared to steels of the type SIS 2562 a weld metal containing more molybdenum should be used for optimum corrosion resistance.

5 CORROSION PROPERTIES IN SERVICE RELATED MEDIA

5.1 Pulp bleaching plants

In the pulp and paper industry the severest corrosion problems exist in the bleach plants, especially in the acidic chlorine (C) and chlorine dioxide (D) stages. Here the environment is also strongly oxidising and appreciable amounts of chlorides may exist in pulp suspensions and filtrates. In the filter washers, great amounts of stainless steel are used and the risk for pitting and crevice corrosion always exists. This is especially true for parts exposed to the gas phase above the pulp suspension (8, 9).
Table 12 shows the results of some field tests. In all test sites, alloys C and D have been completely resistant while SIS 2343 and 2562 were attacked by pitting or crevice corrosion both in the parent metal and in the welds. The parent metal of the Avesta 254 SMO samples was not attacked, but the welds were in two cases. These attacks, however, were relatively mild and they were much shallower than those of the other stainless steels.

Alloy	Weight loss g/m²h	Max depth of attack, mm Plate	Weld	Weight loss g/m²h	Max depth of attack, mm Plate	Weld	Weight loss g/m²h	Max depth of attack, mm Plate	Weld	Weight loss g/m²h	Max depth of attack, mm Plate	Weld
SIS 2343	.26	3	3	.016	0.5	0.5	Penetrated			.12	1	0.5
SIS 2562	.10	2	2	.013	0.2	0.2	.088	0.6	2	.009	0.3	1.0
Avesta 254SMO	.002	0	0.5	.005	0	0	.005	0	0.5	.000	0	0
C	.000	0	0	.001	0	0	not tested			not tested		
D	.000	0	0	.000	0	0	.000	0	0	.000	0	0
Test No	A			B			C			D		
Duration, months	14			6			16			16		
Location	Filter washer			Tower (Redox vessel)			Tower top ventilation			Filter washer		
Av. temp., °C	20			25			20			20		

Table 12: Results of field tests in the gas phase in some C stages. Cross welded samples

5.2 Chlorate production

When sodium or potassium chlorate are produced by electrolysis of sodium chloride a strongly oxidising chlorate solution is formed in the electrolytic cells. This solution attacks most metallic materials except titanium. The corrosiveness of the solution is lower in later parts of the process because the pH of the solution is raised and its oxidising power, mainly caused by hypochlorite, decreases gradually. Normally stainless steel is used from the crystallizers onwards.

In one plant the solution entering the crystallizers has the following average composition:

$NaClO_3$	500 g/l	$Na_2Cr_2O_7$	3 g/l
NaCl	140 g/l	pH	10
NaClO	5 g/l	Temperature	45-20°C

The crystallizer inlet tubes are made of SIS 2343 and in one place they had to be replaced twice a year due to severe pitting corrosion. A welded tube made of Avesta 254 SMO was installed instead and after 15 months of service there were no signs of attack.

5.3 Sea water

Conventional stainless steels containing molybdenum can be used in sea water under certain conditions. The risk for corrosion attacks will be great, however, if crevices exist on the steel surface and if the velocity of movement is low (10). In table 13 and 14 the results of two sea water exposure tests are shown.

Alloy	Number of crevice attacks	Max depth of attack mm
SIS 2343, AISI 316	26 (out of 120)	1.1
SIS 2562	2 (out of 120)	0.2
Avesta 254 SMO	0 (out of 120)	0

Table 13: Crevice corrosion behaviour in low velocity sea water. 0.5 m/sec
Water temperature: 22°C
Exposure duration: 30 days

Alloy	Number of crevice attacks	Max depth of attack mm
SIS 2367, AISI 317L	11 (out of 48)	1.4
SIS 2562	4 (out of 48)	0.2
Avesta 254 SMO	0 (out of 48)	0

Table 14: Crevice corrosion behaviour after immersion in sea water on the Swedish west coast
Exposure duration: 1 year

Both tests must be considered stringent because the sea water had a low velocity and because the test samples were equipped with tight fitting crevices formed by a multiple crevice test assembly

made of plastic (11). The test presented in table 13 was carried out on the US east coast in aerated and filtered sea water. In the other test the samples were exposed at 1 m depth and during the exposure they were covered by marine growth. In this test, grade SIS 2367 was attacked not only under the plastic crevices but also under the growth. The depth of attack, however, was shallower in the latter case.
Avesta 254 SMO was completely resistant to sea water in these severe tests. This is as expected, since a good result in the $FeCl_3$ tests (tables 3 and 5) is considered to indicate a good sea water resistance (12, 13).

5.4 Tall oil destillation

When tall oil is fractionated into tall oil rosin and fatty acids, the crude product is distilled in several stages. The severest corrosion problems exist in the column containing the purest fatty acids. The result of a test performed in a fatty acid column is shown in table 15.

Alloy	Corrosion rate, mm/year
SIS 2343, AISI 316	0.88
W.Nr 1.4439	0.28
Avesta 254 SMO	0.01

Table 15: Result of testing in a fatty acid column in a tall oil destillation plant. Welded samples.
Corrosive environment: Fatty acids 92-97 %
Rosin acids 1-5% Neutrals 2-4%
Acid No 193-197, Temp 235°C
Exposure duration: 1 year

According to earlier experience it is essential that the alloys used in this application are high in molybdenum (14). The very low corrosion rate of Avesta 254 SMO confirms this experience.

5.5 Inorganic acids

Avesta 254 SMO is mainly intended for use in halide solutions or solutions contaminated by halide ions. In such solutions the greatest corrosion hazard is localized attacks such as described in earlier chapters. In certain environments, however, the effect of halides might be an increase in the rate of the uniform corrosion.
This is especially true for very acidic solutions. Phosphoric acid produced by the attack of sulphuric acid on phosphate rock is a typical example of this situation. This acid has a very complex corrosion pattern since it contains both corrosion inhibitors and corrosion activators and the balance between them is critical (15). Table 16 shows the result of testing in two acids that have an unfavourable balance between inhibitors and activators.

Alloy	Corr.rate, mm/year Acid 1 60°C	Acid 2 50°C
SIS 2343	>5	>5
SIS 2562	1.2	0.16
Avesta 254 SMO	0.049	0.15
A	1.3	0.13

Acid composition, % w/w

	Acid 1	Acid 2
P_2O_5	54	26
Cl	0.060	0.034
F	1.1	1.3
H_2SO_4	4.0	1.7
Activators		

	Acid 1	Acid 2
Fe_2O_3	0.27	0.40
Al_2O_3	0.17	0.01
SiO_2	0.10	0.30
CaO	0.20	0.02
MgO	0.70	0.00
Inhibitors		

Table 16: Result of testing in two phosphoric acids, 168 h

The only alloy that has remained passive in both acids is Avesta 254 SMO.
In certain chemical processes the raw material used contains fluorine. Different kinds of fluorine compounds are often enriched in the waste gases and they can cause trouble in ducts and fans. The results of some tests performed in different compounds containing fluorine are presented in table 17.

Alloy	Corrosion rate, mm/year				
	HF 1%, 30°C	HNO_3 + HF 20+4%, 25°C	NH_4HF_2 10%, 25°C	H_2SiF_6, 20% 25°C	40°C
SIS 2343	0.71	9	0.53	0.91	-
SIS 2562	0.12	0.51	0.12	0.23	-
Avesta 254 SMO	0.091	0.31	0.11	0.014	0.10

Table 17:

Result of testing in compounds containing fluorine
168 h

In comparison with the other steel grades tested, the performance of Avesta 254 SMO is especially good in fluosilicic acid, which commonly occurs in the waste gases of phosphoric acid, superphosphate and aluminium plants.
Diagram 1 shows the isocorrosion curves for Avesta 254 SMO and grade SIS 2562 in sulphuric acid up to 50% concentration. The curves valid for a pure acid and an acid containing 200 ppm chloride are given for each steel grade.

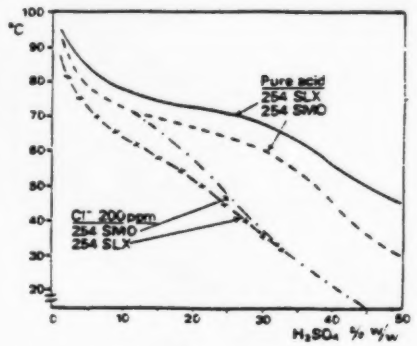


Diagram 1:

Isocorrosion curves, 0.1 mm/year, for Avesta 254 SMO and SIS 2562 in sulphuric acid containing 0 and 200 ppm Cl^-

Grade SIS 2562 is more resistant than Avesta 254 SMO in the pure acid but as little as 200 ppm chloride reverses the situation. The positive effect of the high molybdenum content in Avesta 254 SMO is still more pronounced in dilute acids containing high amounts of chloride. Table 18 shows some examples of this.

Corrosive medium composition, % w/v				Corrosion rate mm/year				
H_2SO_4	Cl^-	SO_2	°C	SIS 2343		SIS 2562		254 SMO
1	0.1		70	0.23	a	0.084		0.008
1	0.1	sat	60	15	b	0.97		0.11
1	1.0		60	1.4	b	0.089	b	0.008
1	1.0	sat	60	>100		6.8		0.11

Key: a isolated pits
b substantial pitting

Table 18: Result of testing in dilute sulphuric acid containing chlorides. 168 h

It should be observed that saturation of the chloride solutions with sulphur dioxide results in rapid general corrosion instead of pitting. Avesta 254 SMO was not attacked by pitting but only by moderate general corrosion.

5.6 Gas cleaning

During flue gas cleaning in wet scrubbers the scrubbing water becomes acidified by the SO_2 and SO_3 content in the gas. If the scrubbing water is recirculated, a high chloride content can be built up and if there is no neutralization the liquid will become strongly acidic. In some cases the chlorides originate from scrubbing with sea water, e.g. in the inert gas systems on tankers. These acidic chloride solutions frequently cause great corrosion problems in gas scrubbers.
Different test solutions are proposed in the literature which should correspond to the composition of the scrubbing water in various kinds of gas cleaning (16-18). Table 19 presents the results of tests carried out in some of these solutions.

Corrosive medium Composition, % w/v	°C	Time h	Ref	Weight loss, g/m²h SIS2343	SIS2562	254SMO	A	C
H_2SO_4 11, HCl 1.2, $CuCl_2$ 1.0, $FeCl_3$ 1.0	50	24	16	23 b	8.8 b	.023	19 b	.010
$NaHSO_3$ 0.2, Cl^- 3.0, pH 4.0	90	192	17	.010 a	.002 a	.001	.002	.002
H_2SO_4 25, NaCl 3.0, H_2SO_3 4.5	50	18	18	100	9.5 b	.96	7.0 b	1.4
H_2SO_3 5.0, NaCl 1.0	50	500	18	.012 a	.048 a	.001	.001 a	.006
Synthetic sea water, pH 1.5	40	4900	18	.009 a	.003 a	.000	.001 a	.001

Key: a crevice or pitting corrosion
b severe crevice or pitting corrosion

Table 19: Result of testing in simulated scrubber environments. Creviced samples

Again, Avesta 254 SMO has a performance close to that of the best nickel alloys.

6 REFERENCES

1 ASTM Designation: G 48-76

2 Garner A: Corrosion/78, Houston March 1978, Paper No. 20

3 Oldfield J W, Sutton W H: Proceedings Eurocorr '77, London Sept 1977, p.239-246

4 Crolet J L, Defranoux J M, Seraphin L, Tricot R: Mem.Sci.Rev.Metallurg. 71(1974):12 p797-805

5 Desestret A, Wagner G H: Werkstoffe und Korrosion 20(1969):4 p.300-305

6 Narayan A, Flint G N: INCO Technical Publication P-MCD 17 (1974)

7 Dundas H J: Climax Molybdenum Report RF-33-74-18 (1975)

8 Wallén B: Pulp and Paper Ind. Corr. Problems, Vol. 2 NACE Houston (1977) p.43-52

9 Liljas M, Wallén B: Pulp and Paper Ind. Corr. Probl., Vol 2, NACE Houston (1977) p.27-32

10 Flint G N: INCO Technical Publication P-BL. 323 (1976)

11 Anderson D B: Galvanic and Pitting Corrosion - Field and Laboratory Studies, ASTM STP 576, 1976 p.231-242

12 Brignam R J, Tozer E W: Corrosion 32(1976):7 p.274-276

13 Deverell H E, Maurer J R: Corrosion/77, San Francisco 1977, Paper No. 97

14 Templeton H C: J. Am. Oil Chemists' Soc., 47(1970) p.138 A

15 Wallén B, Andersson I: Proceedings MariChem 77, Hamburg October 1977, p.171-186

16 Hastelloy and Haynes Corrosion-Resistant Alloys for Pollution-Control Systems. Cabot Corp. 1977

17 Lizlovs E A: Corrosion/76, Houston March 1976, Paper No. 133

18 Glover T J: The International Conference on Air Pollution, University of Pretoria. Apr.1976

AVESTA TECHNICAL INFORMATION

2. 1980

AVESTA 254 SMO —

SOME APPLICATIONS IN THE PULP AND PAPER INDUSTRY

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AVESTA 254 SMO - SOME APPLICATIONS IN THE PULP AND PAPER INDUSTRY

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Stainless steel found one of its first applications in the pulp and paper industry. The development of acid-proof stainless steels was associated with the sulphite process where the acidic cooking liquor caused corrosion problems with the standard 18/8 steels.

The demands of the pulp and paper industry on structural materials have increased considerably over the years. In the continuous processes with their high volume of production, unscheduled stops due to material failures are very expensive. The restrictions on effluents have led to increased chloride levels in the mills, and hence greater risks for corrosion damage. The predominating corrosion attacks on stainless steels caused by chlorides are pitting, crevice corrosion and stress corrosion cracking. The objective of this paper is to present corrosion data of the high molybdenum stainless steel AVESTA 254 SMO and to show some results from field tests in the pulp industry.

AUSTENITIC STAINLESS STEELS WITH HIGH PITTING RESISTANCE

The corrosion properties of stainless steels are mainly dependent on their chemical composition. As the corrosion attacks are, in many cases, especially in chloride solutions, extremely local in nature, the distribution of the alloying elements also plays an important role. Consequently the micro structure can influence the corrosion pattern in many ways.

It is well established that pitting and crevice corrosion resistance is improved by increasing the molybdenum and, to some extent, the chromium content. Today, wrought austenitic stainless steels contain up to about 6 % molybdenum. AVESTA 254 SMO has a typical composition of 20 % Cr, 18 % Ni, 6.1 % Mo and 0.2 % N. Difficulties in producing a homogeneous single phase structure prevent the metallurgists from increasing the molybdenum level of iron-base alloys. Higher molybdenum additions, however, could be made to nickel-base alloys of which some are used in the pulp and paper industry.

An inherent property of high molybdenum austenitic alloys is the tendency to segregate during solidification, i.e. certain elements are unevenly distributed in micro-scale. Hence the weld metal could contain molybdenum variations that make it more prone to localized corrosion than does the homogeneous plate material of the same composition (1). The segregations can be eliminated by post-weld heat treatments. To avoid the risks of corrosion attacks without the use of heat treatment, a high alloy filler metal can be used. For AVESTA 254 SMO the welding material is a nickel-base type containing 21 % Cr and 9 % Mo. Extensive corrosion tests (2) have shown that welded material hereby reaches the same high pitting and crevice corrosion resistance as the homogeneous plate material.

In order to evaluate the corrosion properties of various alloys laboratory tests are normally chosen. Such tests are in many cases accelerated to produce quick results - which are consequently of little use in predicting service life. However, laboratory tests generally give the most reliable values as the test parameters are much better controlled than in field tests. Furthermore, laboratory tests are more dependable when corrosion properties of various alloys are compared. The alloys tested in this work are listed in Table I. The test material was cut from normal 2-3 mm production sheet.

TABLE 1. Chemical composition of tested alloys

Avesta grade	AISI	SS	C max	Typical analysis, % Cr	Ni	Mo	Others
832 SK	316	2343	.05	17	11	2.7	
832 SNR	317L	2367	.03	18.5	14.5	3.4	
832 SL	-	-	0.4	17	15	4.3	
254 SLX	-	2562	.02	20	25	4.5	1.5 Cu
254 SMO	-	-	.02	20	18	6.1	0.7 Cu, 0.2 N
453 S	329	2324	.08	26	5	1.5	
3RE60	-	-	.03	18.5	5	2.7	1.5 Si
A	-	-	.05	21	42	3.0	2.2 Cu, Ti
B	-	-	.10	21	Bal	9	5 Fe, Nb
C	-	-	.02	16	Bal	16	5.5 Fe, Nb
D	-	-	.02	25	4	4	Ti
E	-	2326	.02	18	-	2	Ti
ATi24	ASTM B265 Grade 1 (Commercially pure titanium)						

Pitting corrosion: A common way to determine the resistance against pitting initiation is to measure the pitting potential in a chloride solution. The higher the potential without breakthrough of the passive surface of an alloy, the greater its pitting resistance. Fig. 1 demonstrates a superior pitting resistance for AVESTA 254 SMO as opposed to the other alloys tested.

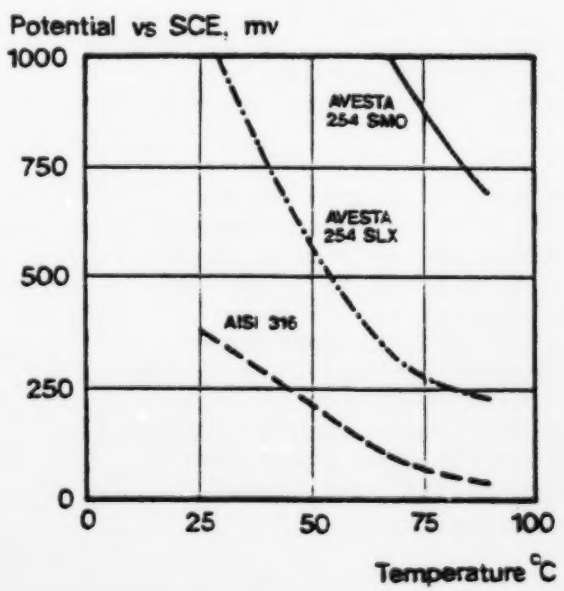

Fig. 1. Pitting potentials in 1M NaCl solution for some alloys, scanning rate 20mV min.

The excellent behaviour of AVESTA 254 SMO is the result of its very high molybdenum content. Another pitting corrosion test that reveals the influence of molybdenum is the 10 % $FeCl_3$ test. In this test the critical temperature is determined above which pitting occurs. A linear increase in CPT (critical pitting temperature) versus increased molybdenum content in the alloy has been observed (3).

Crevice corrosion: Crevice corrosion involves essentially the same electrochemical processes as pitting although the initiation mechanism is somewhat different. As in the case with pitting, an increase in critical crevice corrosion temperature (CCT) with increasing molybdenum content has been observed. This is illustrated by Fig. 2 which shows plots of both CCT and CPT against molybdenum content.

CCT is markedly lower than CPT which indicates that crevice corrosion can occur in a less aggressive environment than does pitting.

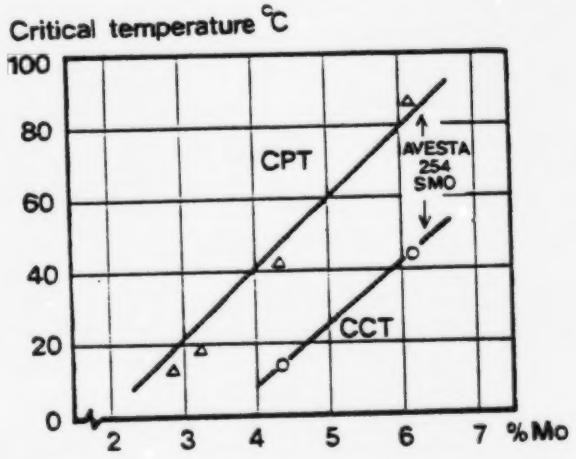

Fig.2. CPT and CCT vs molybdenum content in some alloys (4). Test solution 10 % $FeCl_3$ according to ASTM G48-76.

Stress corrosion cracking (SCC): Many test methods are being used to evaluate SCC properties of various alloys. The results of a conventional test are shown in Table II. Neither the high nickel-content material AVESTA 254 SLX nor AVESTA 254 SMO fractured after 3,000 hr while type 316 fractured in about 450 hr. In a newly-developed SCC test (5) the loaded samples are heated by an alternating current to 300 °C while a dilute chloride solution is dropped onto the surface and evaporates. This test method is believed to simulate the conditions in many practical cases. Data from such a test are given in Table III. Type 316 fractured in about 50 hr while AVESTA 254 SMO failed to fracture even after 1,000 hr.

TABLE II. Results of SCC test

Alloy	Time to fracture h
AISI 316	450
AVESTA 254 SLX	> 3000
AVESTA 254 SMO	> 3000

TABLE III. Results of SCC test

Alloy	Time to fracture h
AISI 316	50
AVESTA 254 SMO	> 1000

SCC evaporation method
Stress: 90 % of Y.S. at 200°C

Process adapted tests: To compare candidate materials for a certain process, laboratory tests could be performed in a simulated process solution. To speed up the results, the conditions of corrosion can be intensified by increasing temperature, acidity or chloride level for example.

Table IV shows some results of crevice corrosion tests in acidic chloride solution simulating the conditions in a bleach plant chlorination washer.

TABLE IV. Crevice corrosion tests in synthetic chlorination washer filtrates

Test	Alloy	Liquid phase		Vapor phase	
		weight loss g/m^2h	max depth mm	weight loss g/m^2h	max depth mm
I	316	0.48	g	0.001	0
	SS 2562	0.018	0.7	0.001	0
	AVESTA 254 SMO	0.001	0	0.001	0
II	316	0.54	1.5	3.2	g
	SS 2562	0.42	1.4	0.72	g
	AVESTA 254 SMO	0.24	1.0	0.50	g

g = general corrosion
I 2000 ppm Cl^-, pH 1.0, temperature 60°C, test duration 144 h
II 2000 ppm Cl^-, pH 1.0, temperature 60°C, Cl_2-bubbling 2 x 10 min every 24 h, test duration 90 h

Without chlorine the corrosion in the vapor phase is almost nil for all three alloys tested. In the liquid phase, however, type 316 was subjected to substantial general corrosion while AVESTA 254 SLX was attacked only in crevices. The AVESTA 254 SMO was fully resistant under these conditions. When chlorine was added the environment became much more aggressive. All alloys were attacked - in vapor by general corrosion and in liquid extensively by crevice corrosion. These results demonstrated that high residual chlorine levels could, even occasionally in the acidic bleach plant stages, cause rapid corrosion damages in both the liquid and gase phase even on the highest alloyed steels. This is consistant with results in field tests and practice (6, 7). Therefore, in closed bleach plants where high chloride contents and low pH values are expected, a close control of free chlorine is necessary for good service with stainless steels.

Another corrosion problem area in the pulp mill is the treatment of effluent gas. In wet SO_2 scrubbers the circulating acidic scrubbing water may contain considerable amounts of chlorides, thus causing frequent pitting and crevice corrosion damage on stainless steels. Various laboratory test solutions for these types of environments have been proposed in literature (8-10).

Some tests performed in simulated scrubber environments are presented in Table V. Type 316 and AVESTA 254 SLX exhibit extensive corrosion while AVESTA 254 SMO compares favorably with nickel-base alloys.

TABLE V. Results of testing in simulated scrubber environments. Creviced samples

Corrosive medium Composition, % w/v	°C	Time h	Ref	Weight loss, g/m^2h 316	AVESTA 254 SLX	AVESTA 254 SMO	Alloy A	Alloy C
H_2SO_4 11, HCl 1.2, $CuCl_2$ 1.0, $FeCl_3$ 1.0	50	24	8	23 b	8.8 b	.025	19 b	.010
$NaHSO_3$ 0.2, Cl^- 3.0, pH 4.0	90	192	9	.010 a	.002 a	.001	.002	.002
H_2SO_4 25, NaCl 3.0, H_2SO_3 4.5	50	18	10	100	9.5 b	.96	7.0 b	1.4
H_2SO_3 5.0, NaCl 1.0	50	500	10	.012 a	.048 a	.001	.001 a	.006
Synthetic sea water, pH 1.5	40	4900	10	.009 a	.003 a	.000	.001 a	.001

Key: a crevice or pitting corrosion
b severe crevice or pitting corrosion

FIELD TESTS AND EXAMPLES USING AVESTA 254 SMO

The most direct way to study the suitability of various materials in a certain process is naturally to expose them in the operating environment. Such studies should extend to some portion of the expected service life in order to provide reliable or even measurable results. In most mill exposures, corrosion test spools described elsewhere (11) were used. After the test, the extent of corrosion was evaluated by weight loss and corrosion depth measurements.

Bleach plants: The chlorination and chlorine dioxide stages in the bleach plant are often considered to be the greatest corrosion problem area in the pulp and paper industry (6). For this reason, many corrosion investigations have been performed in bleach plant environments in recent years (12-16). The general conclusion is that the principal materials of construction - types 316 and 317 - do not show satisfactory performance in the acidic bleaching stages. It has also been observed that the corrosion rates are greater in the gas phase than in the corresponding liquid phase. In the totally enclosed mills of the future an increased corrosiveness is to be expected as the environmental conditions will be more severe.

In a previous paper, various corrosion investigations in connection with bleach plant environments were presented (7). Data from some field tests were also given. The results of continued gas phase exposures in four chlorination stages are presented in Table VI.

TABLE VI. Results of field tests in the gas phases in some C stages. Cross welded samples

Test No Duration, months Location Av temp °C	A 14 Filter washer 20			B 6 Tower (Resox vessel) 25			C 16 Tower top ventilation 20			D 16 Filter washer 20		
Alloy	Weight loss g/m²h	Max depth of attack, mm plate	weld	Weight loss g/m²h	Max depth of attack, mm plate	weld	Weight loss g/m²h	Max depth of attack, mm plate	weld	Weight loss g/m²h	Max depth of attack, mm plate	weld
AISI 316	.26	3	3	.016	0.5	0.5	Penetrated			.12	1	0.5
AVESTA 254 SLX	.10	2	2	.013	0.2	0.2	.088	0.6	2	.009	0.3	1.0
AVESTA 254 SMO	.002	0	0.5	.005	0	0	.005	0	0.5	.000	0	0
C	.000	0	0	.001	0	0	not tested			not tested		
AT i 24	.000	0	0	.000	0	0	.000	0	0	.000	0	0

Type 316, and to some extent also AVESTA 254 SLX, were severely attacked in both parent metal and weld while AVESTA 254 SMO had no sign of attack in the parent metal. Shallow pits were detected in two welds. The used filler metal, however, was of the same composition as the plate material. The results illustrate the previously mentioned fact that in using high molybdenum alloys, special over-alloyed welding material should be used. Alloy C and titanium remained unattacked in all tested locations. The samples from mill A are shown in Fig. 3.

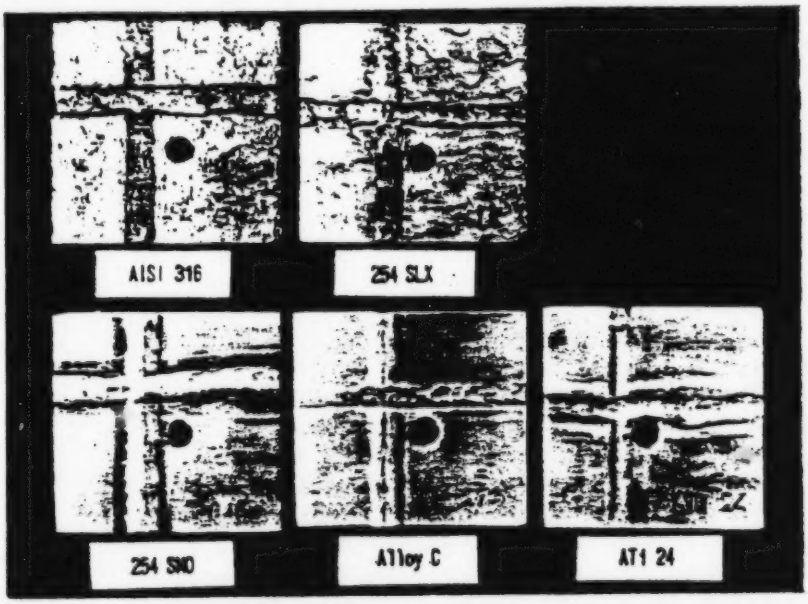

Fig. 3. Appearance of test samples after exposure 14 months in a chlorination filter washer (mill A)

The very promising results with AVESTA 254 SMO have been confirmed in practice. In a Swedish bleach plant the filter washer vats for the Cl_2 and ClO_2 stages were made of type 317L. After 9 months of operation severe pitting was found, especially on the parts of the inlet box exposed to the gas phase. Repairs were made with AVESTA 254 SLX. Even this alloy suffered profuse pitting in the gas after 6-12 months. The most corroded areas were lined with AVESTA 254 SMO which has been in service for over 2 years without any sign of attack. Filter vats and drums for chlorination and chlorine dioxide washers are now being built of AVESTA 254 SMO.

Scrubbers: In a corrosion testing program in Swedish mills, test spools were distributed and evaluated by the Swedish Corrosion Institute. The results from an exposure in the scrubber of a kraft recovery boiler are presented in Table VII.

TABLE VII. Results of a field test in a flue gas scrubber of a kraft recovery boiler

Alloy	ATi24	B	C	AVESTA 254 SMO	D	AVESTA 254 SLX	A
Corrosion rate, mm/y	0.00	0.03	0.05	0.10	0.12	0.92	2.8

Test duration: 127 days. Environmental conditions: SO_2 1000 ml/m^3, H_2S 10 ml/m^3, HCl 50 ml/m^3, temperature 65°C. Welded samples

Out of 13 alloys tested, 6 were lost due to rapid corrosion. The latter alloys included types 316, 317, 329, 18-2 Mo, AVESTA 3RE60. and AVESTA 832 SL. The remaining 7 samples exhibit general corrosion although slight crevice corrosion was observed on alloy D and slight pitting on AVESTA 254 SLX. The weight losses can consequently be converted into corrosion rates. Titanium was completely resistant in this test. Alloys B, C, D and AVESTA 254 SMO show very low corrosion rates (in the range 0.03-0.12 mm/yr) while AVESTA 254 SLX and alloy A show notable corrosion. As in the laboratory tests, AVESTA 254 SMO has a performance close to that of the best nickel-base alloys where standard materials do not apparently suffice.

In a kraft mill the gases from two recovery boilers enter the wet scrubber at 165 °C and the circulating washing water has a pH of 7, a temperature of 70 °C and a chloride content of 4000 ppm. The scrubber was originally made of type 316 but due to pitting corrosion the lower parts of the scrubber had to be relined several times. More than a year ago 316 was replaced with AVESTA 254 SMO in the lower parts of the scrubber. No attacks have been observed.

Tall oil distillation: Some of the most aggressive compounds involved in tall oil distillation are the fatty acids. As the temperature is high, type 316 normally gives an unsatisfactory service life. Table VIII illustrates the beneficial influence of the molybdenum content on corrosion resistance in a fatty acid column. The corrosion rate measured on AVESTA 254 SMO is almost negligible. The results are consistent with service experience. Due to the high corrosion on type 316, the principal construction material being used today in distillation columns in Swedish plants is AVESTA 832 SL.

Alloy	Corrosion rate, mm/year
AISI 316	0.86
AVESTA 832 SL	0.29
AVESTA 254 SMO	0.01

TABLE VIII. Result of testing in a fatty weld acid column in a tall oil distillation plant. Welded samples. Corrosive environment: Fatty acids 92-97 %. Rosin acids 1-5 %. Neutrals 2-4 %. Acid No 193-197. Temp 235°C. Exposure duration: 1 year.

Although noticeable corrosion rates can be expected also with this alloy, sufficient wall thicknesses can be chosen for obtaining the desired service lives. However, certain critical equipment has to be made of more resistant material to ensure its function. A Swedish plant is, therefore, going to employ AVESTA 254 SMO 0.16 mm wire for woven mesh to be used as a column packing.

Chlorate production: The production of sodium or potassium chlorate involves oxidizing solutions with high chloride contents. The corrosiveness of the environment depends on its pH value and oxidizing power. In neutral or acidic solutions, stainless steels are attacked. This is shown in Table IX.

Alloy	Alloy performance, 444 h Weight loss g/m^2h	Remarks
AISI 316	1.7	Severe pitting, particularly in weld.
AVESTA 254 SLX	0.04	Pitting corrosion, particularly in weld.
AVESTA 254 SMO	0.002	Slight pitting corrosion.
Ti24	0.000	No attacks.

Table IX. Results of field tests in a sodium chlorate reaction vessel, welded samples.
Average corrosive environment:

$NaClO_3$	220 g/l	pH 6.5-7
NaCl	115 g/l	Temperature 45°C
NaClO	5 g/l	
$NaCr_2O_7$	3 g/l	

Although AVESTA 254 SMO was much more resistant than the other stainless steels tested, there were slight localized attacks even on this grade. Titanium should therefore be a safer choice of material.

At higher Ph values, however, the environment is less aggressive. In the plant above, the solution which is fed into the crystallizer has the following average composition:

$NaClO_3$	500 g/l	$NaCr_2O_7$	3 g/l
NaCl	140 g/l	pH	10
NaClO	5 g/l	temperature	45-20°C

Originally the crystallizer inlet tube was made of type 316. Due to pitting corrosion it had to be replaced every six months. A tube made of AVESTA 254 SMO has now been in service for two years without any sign of attack.

REFERENCES

1. GARNER, A, Pulp and Paper Industry Corrosion Problems, Vol 2, NACE, Houston, Tex (1977) pp. 87-93

2. WALLÉN, B, and LILJAS, M, Proceedings 8th Scandinavian Corrosion Congress, Vol II, Helsinki (1978) pp. 196-204

3. BRIGHAM, R. J. L., and TOZER, E. W., Corrosion 30 (1974):5 pp 161-166

4. GARNER, A, Corrosion/78, NACE, Houston, March (1978) Paper No 20

5. HENRIKSON, S and ÅSBERG, M. To be published

6. WALLÉN, B, Pulp and Paper Industry Corrosion Problems, Vol 2, NACE, Houston, Tex (1977) pp 43-52

7. LILJAS, M, and WALLÉN, B, Pulp and Paper Industry Corrosion Problems, Vol 2, NACE, Houston, Tex (1977) pp 27-32

8. Hastelloy and Haynes Corrosion-Resistant Alloys for Pollution-Control Systems. Cabot Corp. (1977)

9. LIZLOVS, E. A., Corrosion/76, NACE, Houston, March (1976), Paper No 133

10. GLOVER, T. J., The International Conference on Air Pollution, University of Pretoria, April (1976)

11. CHAMPION, F. A., Corrosion Testing Procedures, Chapman and Hall, London (1964) p 177

12. LALIBERTÉ, L. H., MUELLER, W. A., and SHARP, W. B. A., Corrosion/78, NACE, Houston, March (1978) Paper No 15

13. SHARP, W. B. A., and LALIBERTÉ, L. H., Corrosion/78, NACE, Houston, March (1978) Paper No 16

14. NORDIN, S., KLOOW, G., and GROCKI, J. M., Pulp and Paper Industry Corrosion Problems, Vol 2, NACE, Houston, Tex (1977) pp 17-22

15. AHLERS, P. E., Pulp and Paper Industry Corrosion Problems, Vol 2, NACE, Houston, Tex (1977) pp 23-26

16. LALIBERTÉ, L. H., and SHARP, W. B. A., Pulp and Paper Industry Corrosion Problems, Vol 2, NACE, Houston, Tex (1977) pp 33-42

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